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REPORT ON IOWA ELECTRIC HOUSE-HEATING STUDY - 1958 1/

by Landy B. Altman, Jr. and Leon F. Charity 2/

Studies of the load and operating characteristics of a number of resistance-type electric house-heating systems were made in Iowa during the 1956-57 and 1957-58 heating seasons. Information obtained during the 1956-57 season has been published (1, 2) 3/. A report on the additional findings obtained from data collected in 1957-58 is presented in this paper.

ELECTRIC LOAD CHARACTERISTICS

Procedure and Instrumentation

The five central Iowa power suppliers cooperating in this study each selected four farms with electrically heated houses for this study. Where possible, each power supplier selected at least one house heated with ceiling cable, one with baseboard heaters, and one with glass panels. Some of the heating systems used line-voltage, and others used two-stage low-voltage thermostats. Fifteen-minute, block-interval-type recording demand meters were used to record the electric demands of the heating systems and the other electric loads on the farms. The metering period was from January 13 to February 10, 1958. Recording demand meters installed on the yard pole of one of the farms are shown in figure 1.

A survey form was filled out for each farm showing data about the heating system, house construction, and the appliances owned. The annual energy consumption for house heating and for other purposes was obtained from records of the power suppliers.

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2/ The authors, located at Iowa State College, Ames, are, respectively, Agricultural Engineer, Agricultural Engineering Research Division, ARS, USDA, and Associate Professor of Agricultural Engineering, Iowa State College.

3/ Numbers in parentheses refer to Literature Cited, p. 12.

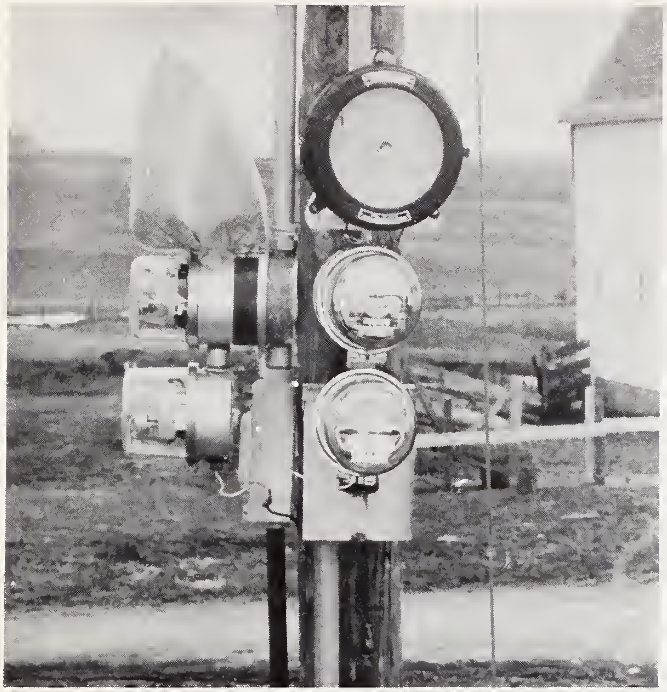

Figure 1.--Recording demand meters installed on yard pole of farm using separate service for electric house heating.

Data on the Houses

Table 1 shows the types of heating units and thermostats, floor areas, connected loads, and annual energy consumptions.

Minimum insulation standards for electrically heated houses in Iowa were met in that at least the equivalent of 4 (actually 3-5/8) inches of mineral-wool insulation was in the sidewalls, 6 inches in the ceiling, 2 inches under floors over basement and between floors, and 4 inches over unheated crawl areas. Windows and doors had weather stripping and either double insulating glass or storm sash.

Sixteen of the heating systems had time-clock-controlled relays to reduce the voltage from 240 to 120 at the time of the distribution-system peak. Ten of these used low-voltage thermostats, each thermostat having a relay, and six used line-voltage thermostats. All of the low-voltage thermostats were of the two-stage type, which normally caused the heater units to cycle between 120 volts and "off" in mild weather and between 240 and 120 volts in cold weather. The line-voltage or single-stage thermostats operated on 240 volts except during the off-peak period, when a master relay switched the heating system from 240 to 120 volts.

Demand and Diversity Factors

The maximum demands of 13 heating systems occurred on February 7, 8, and 9 when lowest temperatures at Ames, Iowa, were respectively, -4°, -8°, and -11° F. As the other seven systems had only slightly higher maximum demands occurring on other days of the metering period, the demand meter records were completely tabulated and analyzed only for February 7, 8, and 9. Information from these tabulations as well as the maximum values for the entire metering period are shown in table 2. As the lowest temperature of the heating season did not occur during the metering period, annual maximum demands probably were higher than those recorded.

Table 1.--Description of electrically heated houses, Iowa 1958.

Farm	Heating units 1/	Floor area of house	Connected heating load: House	Connected heating load: Basement	Total connected farm load (less heating load)	Annual energy consumption: Heating	Annual energy consumption: Other
No.	Type	Sq. Ft.	Kw.	Kw.	Kw.	Kw.-hr.	Kw.-hr.
		TWO-STAGE LOW-VOLTAGE THERMOSTATS WITH OFF-PEAK CONTROLS					
(1)	CC	1,676	18.2	4.8	29.9	19,595	11,670
(2)	CC	1,683	17.8	4.8	48.0	20,097	18,750
(3)	CC	1,550	15.0	4.8	23.1	21,941	15,179
(4)	GP	1,205	16.0	0	52.8	17,170	8,490
(5)	CC	916	10.9	4.8	27.2	11,350	8,680
(6)	CC	1,208	11.4	4.8	12.4	19,580	6,370
(7)	GP	1,300	15.0	0	22.7	15,790	4,760
(8)	GP	1,684	12.0	0	11.9	15,100	5,950
(9)	CC	1,500 2/	14.3	6.1	42.2	35,400 2/	
(10)	CC	1,335	14.6	0	36.5	16,142	8,081
Ave.		1,395	14.5	5.0 3/	30.7	17,418	9,770
		SINGLE-STAGE LINE-VOLTAGE THERMOSTATS WITH OFF-PEAK CONTROLS					
(11)	BB	1,262	13.0	0	38.6	14,906	14,560
(12)	BB	1,268	12.0	4.8	35.8	10,117	9,320
(13)	BB	1,502	20.6	0	22.9	17,447	11,370
(14)	BB	2,400 2/	14.0	4.8	36.7	42,790 2/	
(15)	BB	1,578	11.0	4.5	27.8	14,849	7,488
(16)	CC	1,400	13.0	4.8	26.0	13,714	6,941
Ave.		1,402	13.9	4.7 3/	31.3	14,207	9,936
		TWO-STAGE LOW-VOLTAGE THERMOSTATS WITHOUT OFF-PEAK CONTROLS					
(17)	CC	2,198	32.0	9.6	35.3	24,435	16,215
(18)	GP	1,824	14.0	4.8	28.5	16,034	11,979
(19)	CC	1,400	14.4	4.8	38.2	17,205	8,715
(20)	GP	1,964	23.5	4.8	31.4	17,900	13,079
Ave.		1,847	21.0	6.0	33.4	18,894	12,497
Overall average		1,497	15.6	5.2 3/	31.4	16,854	10,422

1/ CC - Ceiling Cable
GP - Glass Panel
BB - Baseboard

2/ One meter only, not included in averages.

3/ Average of basement heaters.

Table 2.--Diversity between heating and other demands, Iowa 1958.

Farm	Max. 15-min. demand Feb. 7-9			Heating demand factor 1/	Diversity factor between heating and other loads	Max. 15-min. demand Jan. 13 - Feb. 10	
	Heating	Other loads	Heating plus other loads			Heating	Other farm loads
No.	Kw.	Kw.	Kw.	Percent		Kw.	Kw.
(1)	14.6	6.2	17.8	80.2	1.17	14.6	7.6
(2)	11.6	11.6	17.0	67.4	1.37	12.0	12.4
(3)	12.8	(2)	(2)	85.3		12.8	5.2
(4)	11.8	4.8	13.6	77.5	1.22	12.4	4.8
(5)	8.0	3.4	10.0	73.4	1.14	8.0	4.2
(6)	11.2	1.6	12.4	74.1	1.03	12.0	2.4
(7)	8.4	(2)	(2)	56.0		8.4	4.8
(8)	9.4	2.4	10.6	78.3	1.11	9.4	3.4
(9)	12.8	8.6	18.8	77.4	1.14	15.8	8.6
(10)	9.4	5.8	10.8	64.4	1.41	9.4	6.2
(11)	10.0	7.6	14.6	76.9	1.20	10.0	11.6
(12)	7.8	4.2	10.6	65.0	1.13	7.8	10.8
(13)	11.2	5.4	14.0	54.4	1.19	11.2	6.8
(14)	14.6	10.6	17.6	80.8	1.43	15.2	10.6
(15)	11.2	3.6	12.6	72.3	1.18	11.2	4.8
(16)	9.6	5.6	12.2	73.8	1.25	9.6	9.4
(17)	13.0	7.4	17.4	40.6	1.17	13.0	11.2
(18)	10.0	10.0	16.4	71.4	1.22	10.0	10.0
(19)	8.6	4.4	10.0	66.7	1.30	9.6	6.8
(20)	9.2	(2)	(2)	52.8		12.4	8.6
Ave.	10.8	6.1	13.9	69.4	1.22	11.2	7.5

1/ Calculated from heating maximum 15-minute demands and heating connected loads less basement except for farms 6, 9, 14, and 15. The 4 latter farms would have had demand factors above 1.0 if basement heaters were excluded from the connected load; therefore, it can be assumed that the basement heaters operated during the peak period and should be included in the connected load.

2/ Illegible record.

The maximum heating demands and other maximum farm demands are shown in table 2, columns 2 and 3 for the period February 7 to 9, and columns 7 and 8 for the entire metering period. The maximum demands of the heating plus other farm loads for the 3-day period are shown in column 4. Individual heating-system demand factors averaged 69.4 percent when calculated as explained in the footnote of table 2. The low average demand factor indicates that many of the heating systems had excess capacity. This would probably be true for temperatures even lower than the -11° F. recorded during the study.

Diversity factor is defined as the ratio of the sum of the individual maximum demands to the maximum demand of the group. In table 2, column 6, are shown individual diversity factors between house heating and other farm demands. The average individual diversity factor of 1.22 means the total demand of the average farm was 82 percent of the sum of the maximum house heating and other electrical demands. This information may be of use in transformer-loading studies.

The diversity factor among the 20 heating systems was 1.50. This value is relatively high in comparison to other studies of electric heating systems (1) and was undoubtedly caused by the lack of cold windy weather during the metering period. Several days of severe weather conditions would have caused all of the heating systems to have high demands at the same time.

The diversity factor between the group heating-system maximum demand and the group other-farm-loads maximum demand was 1.025. This low value indicates that the demands of both groups were near a maximum at the same time. The off-peak controls used on 16 of the 20 farms resulted in the house-heating group demand being high at the end of the control period, which was a time when other farm demands were relatively high. This indicates that as use of controlled house heating increases, artificial demand peaks may be caused on present typical rural distribution systems.

Group Demands

The daily load curves shown in figure 2 were obtained by averaging the demands for each 15-minute interval for the day of February 8. Curves are shown for the heating systems, other farm loads, and for the heating systems plus other farm loads.

The heating-system load curve clearly shows the off-peak control period as existing from 5:15 to 6:45 p.m. and also the peak demand which follows the control period. It may be of interest to note that the average other farm demands were a maximum during the off-peak period and remained high for some time after the peak period. The heating system plus the other farm demands reached a peak at the end of the control period, 6:45 p.m., and remained as a peak until 7 o'clock.

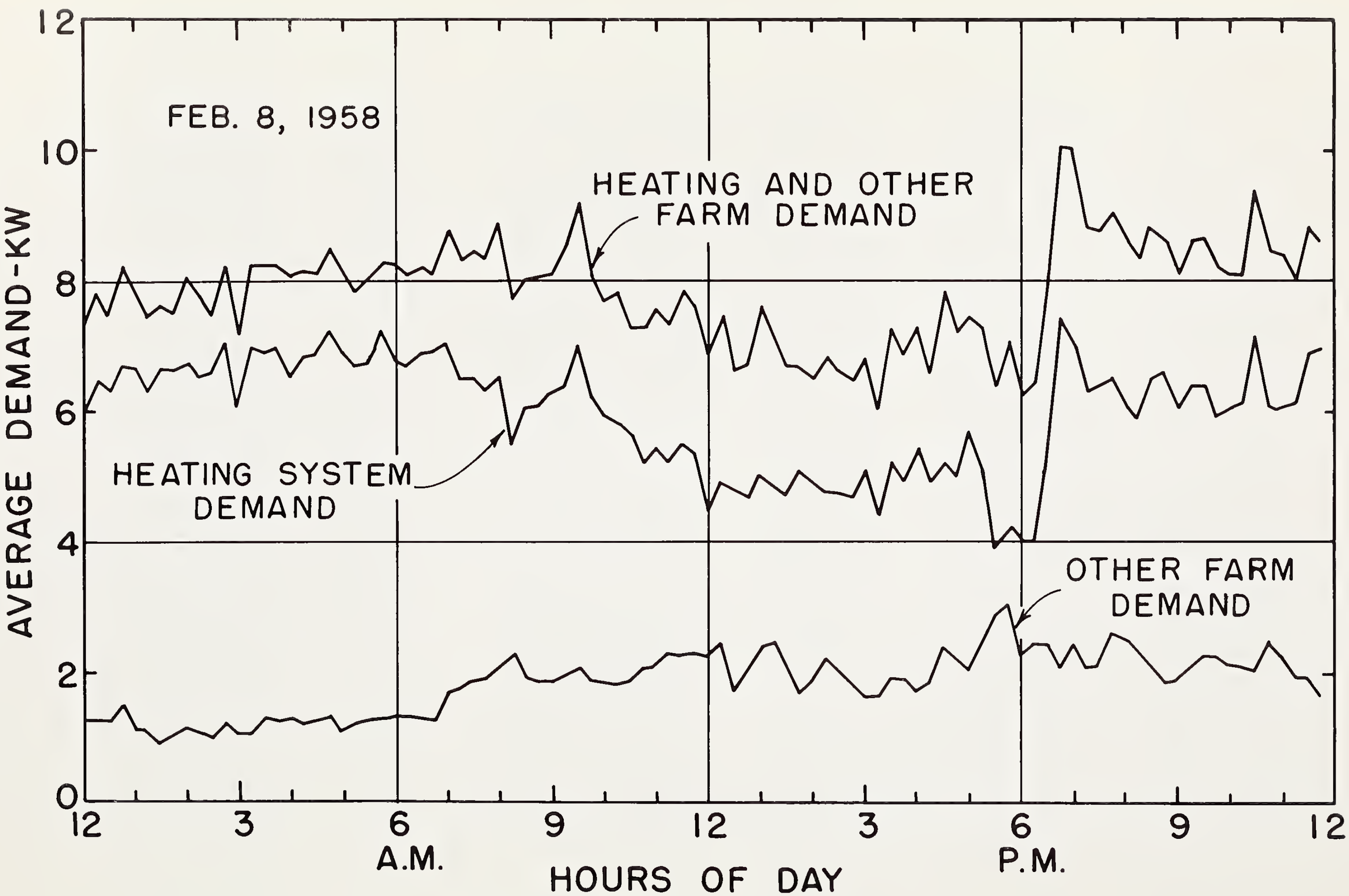

Figure 2.--Comparison of the average demands of 20 electric heating systems with other farm loads - Iowa 1958.

Annual Load Factors

If it is assumed that the peak demands obtained during the 4-week metering period were the annual peak demands, then the annual load factors of the 20 heating systems would average 17.8 percent; those of the other farm loads 19.5 percent; and those of the heating system plus other farm loads 22.4 percent. The latter value is similar to average annual load factors found in other studies for farms without electric house heating (3, 4).

Power suppliers are usually more interested in group load factors than in those of individual farms. The annual group load factor for the heating systems was 25.6 percent and for the other farm loads 38.4 percent. The use of off-peak controls caused the heating system and probably the annual group maximum demand to be higher, thus the annual group load factor lower, than would have been the case without controls.

The diversified load factor, which makes use of the demands that occurred at the time of the distribution-system peak, may be of particular interest to power suppliers. Rural distribution-system peaks now occur at the time of the other farm-load group maximum demand since house-heating saturations are low. In this study the maximum demand period was 5:45 to 6:00 p.m., as shown in figure 2. Using the house-heating demand value for this time period, the group annual load factor for the 20 heating systems, 16 with off-peak controls, was calculated to be 44.7 percent. This value was almost the same as that found in an earlier study (1). The annual load factor for the other farm loads was, of course, the same as before--38.4 percent. The load factor of the heating system plus other farm loads was 43.9 percent.

Effect of Thermostat Type on Demand

The 16 farms with off-peak controls are classified in table 1 according to the type of thermostat used with the heating system. The February 8 average daily load curves for the 10 farms with two-stage (low-voltage) thermostats and for the 6 farms with single-stage (line-voltage) thermostats are shown in figure 3. ("Two-stage" and "single-stage" will designate thermostat type in the remainder of this paper.) Figure 4 shows the average daily load curves for these farms during the off-peak periods and times of system peaks on February 7 and 9. It may be noted from these curves that the average demand of the heating systems using single-stage thermostats dropped much lower at the time of the off-peak period than those using two-stage thermostats. This result is due to the operational characteristics of the two types of thermostats.

The single-stage thermostat places either 240 or zero volts across the heater terminals except during the control period. At the start of this period a clock-controlled relay switches the voltage to the heaters from 240 to 120 volts. The two-stage thermostat places 240, 120, or zero volts across the heater terminals except during the off-peak control period when

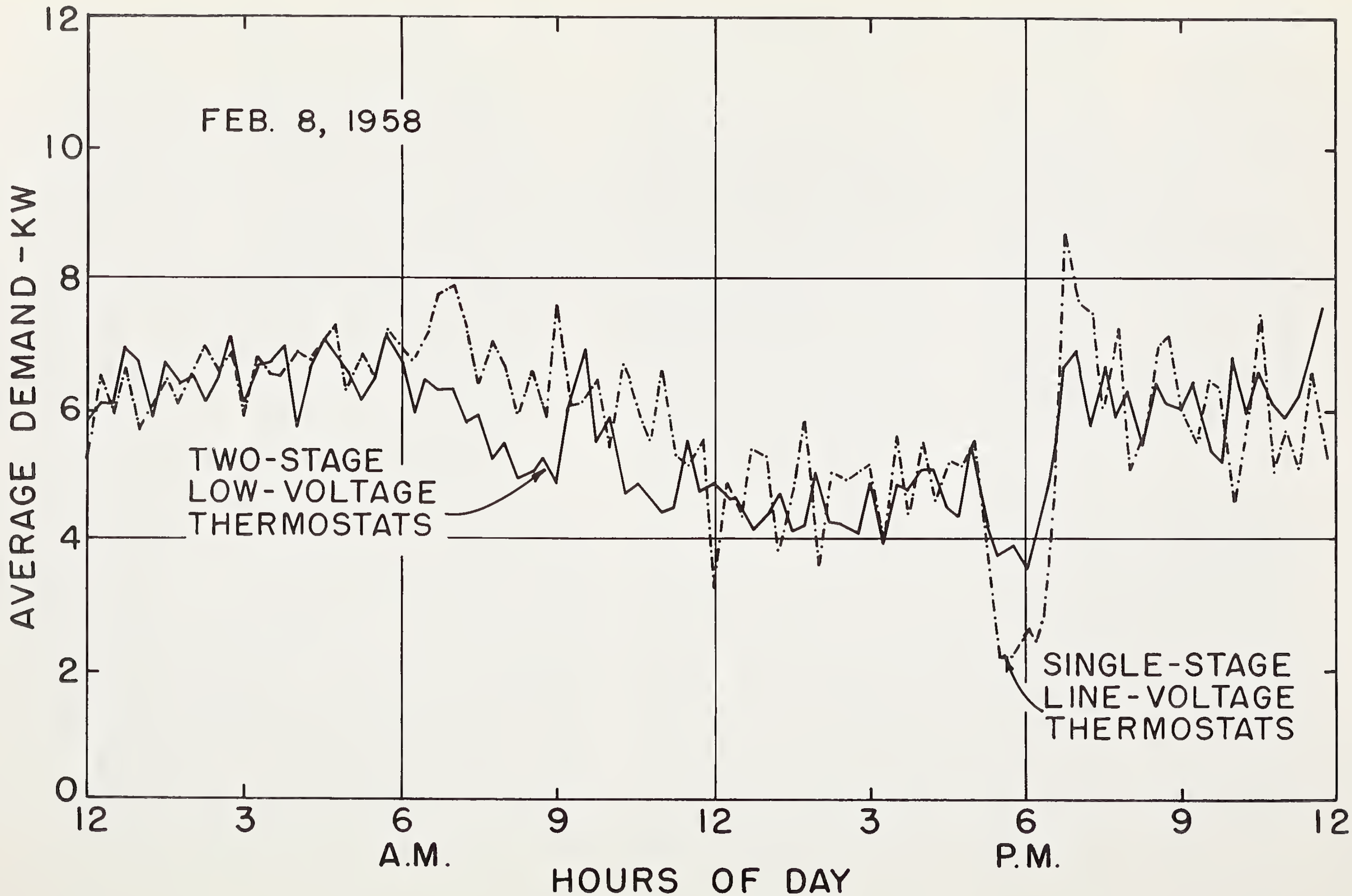

Figure 3.--Average demands of 6 electric heating systems using single-stage thermostats and 10 systems using two-stage thermostats - Iowa 1958.

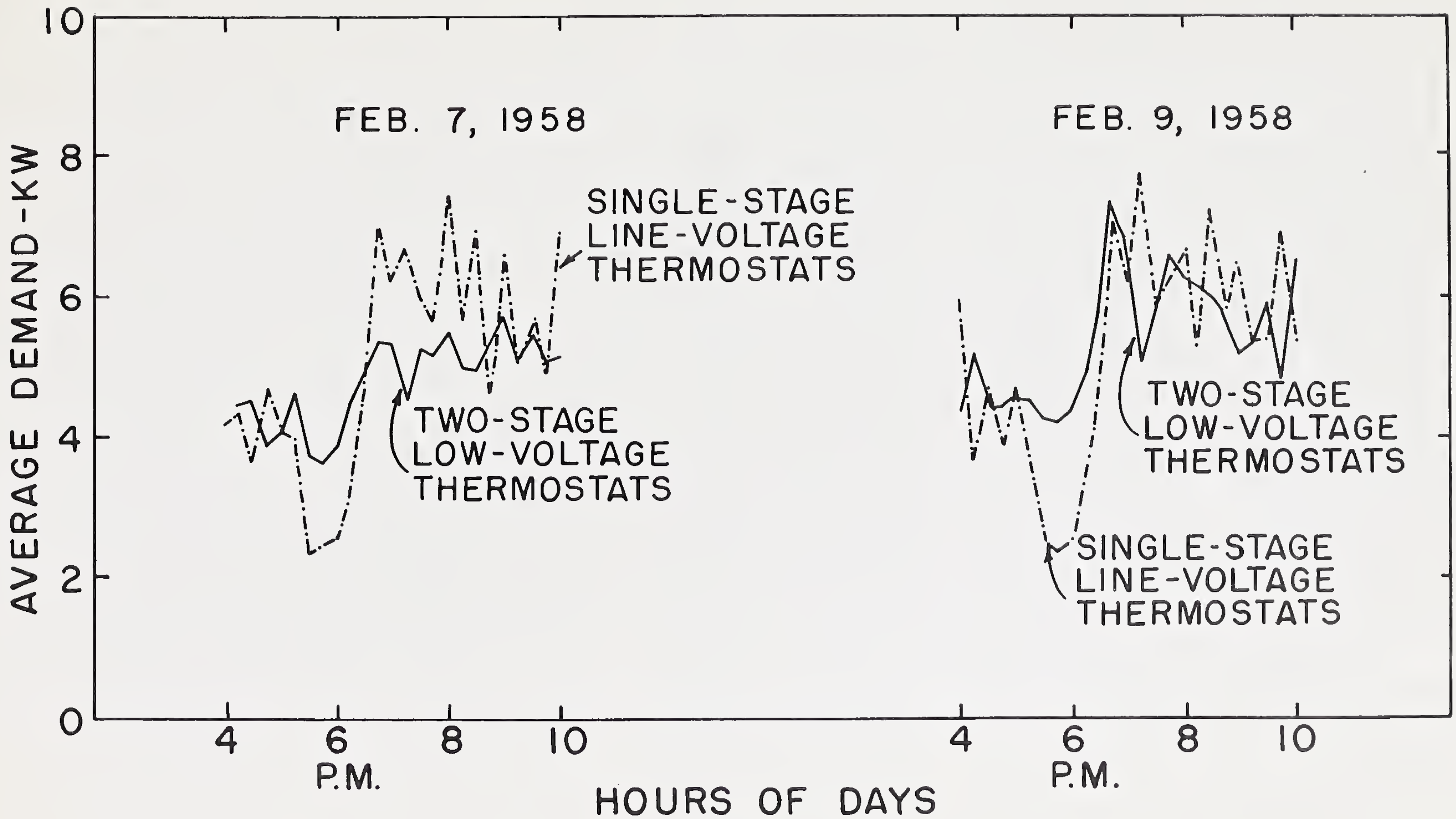

Figure 4.--Average demands of 6 electric heating systems using single-stage thermostats and 10 systems using two-stage thermostats at off-peak periods and times of system peaks - Iowa 1958.

relays operated by the clock and the thermostats place 120 or zero volts across the heaters. A two-stage thermostat has two temperature-sensing elements, one set to operate at a higher temperature than the other. The one set for the higher temperature opens or closes the 120-volt circuit, and the other element opens or closes the 240-volt circuit to the heater. If the heat input resulting from the 120-volt supply does not satisfy the temperature setting of the higher-voltage stage, the second element closes and the heater voltage is increased to 240. Relays in conjunction with the sensing elements interrupt the neutral wire before the 240 volts are applied.

Relative to the heating-system connected loads for houses with single-stage thermostats (table 1) and to their metered-demand values (figures 3 and 4), it is calculated that the demand just before the control period resulted from approximately one-third of the total connected heater load. The remainder of the elements were not energized. At the start of the off-peak period, therefore, only those heating elements in operation were immediately affected by the change from 240 to 120 volts, which reduced the wattage of each heater in operation to one-fourth the normal rating.

Theoretically, for the single-stage system, at the start of the control period, the total demand would be 1/4 times 1/3 or 1/12 of the 13.9 kw. average installed wattage, averaging 1.16 kw. per heating system. The lowest metered 15-minute demand during the control period was considerably greater, 2.20 kw., or about 1/6 of the connected load. The difference between the theoretical and the metered demands was caused by the fact that the former was an instantaneous value and the latter was the average value for a 15-minute period. During this period some thermostats closed and energized additional heaters, which made the average demand higher than the instantaneous theoretical value.

Heating systems with two-stage thermostats had different demand patterns during off-peak control periods from those with single-stage thermostats. An analysis of demands on February 7, 8, and 9 follows to explain the action of the controls on these days.

Practically all heaters with two-stage thermostats should have been operating on either 120 or 240 volts since outside temperatures were near zero on February 7, 8, and 9. It may also be assumed that no basement heaters were in use on these days as the owners were asked to record use of basement heaters and none indicated that they had used them. With these assumptions and by using the values for two-stage thermostats shown in table 1 and in figures 3 and 4, one may calculate that 84.5 percent of the connected load was on 120 volts and 15.5 percent on 240 volts on February 8 when the off-peak control period started. The drop in wattage during the off-peak control period for February 8 would be 15.5 percent times the connected load times 3/4, or 1.69 kw. This is compared to the 3.48 kw. drop in wattage for heating systems with single-stage thermostats.

The theoretical demand of the two-stage system during the control period on February 8, with the assumption of no basement heaters on and all other heaters operating, would be 1/4 of the average installed wattage, or 3.63 kw. The minimum metered 15-minute demand of the control period was 3.56 kw., which is practically the same as the theoretical value. The reasons for the closeness of these values were that the requirements for heat prevented the thermostats from deenergizing any heaters and the controls prevented 240 volts from being supplied to the heater circuits.

In weather cold enough for all heaters to be on 240 volts at the start of the off-peak control period there would be no difference in demand during the control period between heating systems with two-stage and single-stage thermostats. In mild winter weather the demands of heating systems with two-stage thermostats would be reduced very little during the control period since few, if any, heaters would be operating on 240 volts at the start of the control period. The demands of heating systems with single-stage thermostats, however, would be considerably reduced during this period because some heaters just before the control period would have been operating on 240 volts. The actual reduction would not be as great as indicated because other heaters would be thermostatically placed across 120 volts to meet the requirements for heat that had been previously supplied by the heaters on 240 volts. These additional heaters would be placed in operation with differing time delays because of thermostat operating differentials.

The greater reduction in demand during the control period for houses with single-stage thermostats probably resulted in more of a temperature drop than occurred in the systems with two-stage thermostats. This is indicated in figures 3 and 4, where higher peak demands follow the off-peak period for the single-stage systems.

SUMMARY

The demands of the heating systems and other electric loads on 20 farms were metered for the period January 13 to February 10, 1958. The electric heating systems averaged 15.6 kw. of connected load and had an average maximum demand of 10.8 kw., giving a demand factor of 69.4 percent. Diversity factors between the house heating and other loads for the individual farms averaged 1.22. The group diversity factor between house heating and other farm loads was 1.025. Energy consumption averaged 16,854 kw.-hr. per house for the 1957-58 heating season.

The annual load factors for the individual heating systems averaged 17.8 percent, those of the other farm loads 19.5 percent, and those of the combined heating and other farm loads 22.4 percent. The annual group heating load factor was 25.6 and that of the other farm loads was 38.4 percent. The annual group load factors with the maximum demands taken at the time of the system peak were 44.7 percent for heating, 38.4 percent for other farm loads, and 43.9 percent for heating plus other farm loads.

Demands of heating systems using single-stage and two-stage thermostats were compared at the time of the off-peak control period during cold weather. The heating system with single-stage thermostats added a minimum of 2.20 kw. to the distribution-system demand during the control period; the system with two-stage thermostats added a minimum of 3.56 kw.

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